

FOREGROUND CONTRIBUTIONS TO 0.2-2° CMB ANISOTROPIES

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Abstract: We examine the extent to which galactic and extragalactic foregrounds can hamper the detection of primordial Cosmic Microwave Background (CMB) anisotropies. We limit our discussion to intermediate angular scales, $10' \lesssim \theta \lesssim 2^\circ$, since many current as well as future experiments have been designed to map CMB anisotropies at these angular scales. In fact, scales of $\gtrsim 10'$ are of crucial importance to test both the conditions in the early Universe and current theories of the gravitational collapse.

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1 INTRODUCTION

Our purpose here is to re-estimate the contributions of the Galaxy and of discrete extragalactic sources to the Cosmic Microwave Background (CMB) fluctuations, focusing on intermediate angular scales, $10' \lesssim \theta \lesssim 2^\circ$. These angular scales are soon becoming the most interesting ones to confirm the *COBE* DMR detection of large-scale primordial anisotropies (Smoot et al. 1992; Wright et al. 1992). In fact, scales of order 0.2 - 2° provide crucial information on the nature of dark matter, the existence of topological defects, the thermal history of the Universe and the imprints left on the CMB by gravitational effects after the recombination. Thus sensitive observations of the CMB anisotropy at $\lesssim 2^\circ$ resolution are probably one of the most important tools of observational cosmology.

Given the very strong interest on the subject, many ground-based and balloon-borne as well as satellite experiments have recently been developed or proposed to study CMB anisotropies at these angular scales. The atmospheric emission is a serious problem for ground-based experiments while it is largely alleviated in balloon ones. On the other hand, galactic and extragalactic foregrounds are a major problem for any kind of experiment aiming to push the uncertainties at the $\Delta T/T \simeq 10^{-6}$ level. Therefore, a thorough analysis of the foreground emission, spanning the whole wavelength range from ~ 1 cm down to 400 - $500 \mu\text{m}$, is of great interest to identify the best spectral window where foreground anisotropies reach their minimum value. As pointed out by Brandt et al. (1994), multi-channel anisotropy measurements spanning two or three octaves in frequency near the minimum region could perform very well in distinguishing between truly primordial anisotropies and foreground ones.

The galactic radio continuum emission, which is the major source of the diffuse background below ~ 0.5 - 1 GHz, still gives the dominant contribution to the foreground radiation up to $\nu \sim 100$ GHz, due to the combined synchrotron and free-free emissions. At higher frequencies, beyond the minimum at 80 - 120 GHz, emission from interstellar cold dust starts to dominate and even around the intensity peak of the CMB the Galaxy still yields a background relevant to our estimates of the CMB intensity fluctuations. Anyway, galactic foreground fluctuations can be estimated and possibly removed using multifrequency data, providing that the spatial and spectral regions where this foreground is large are avoided.

Concerning extragalactic radio sources, it is now possible, thanks to the recent very deep

VLA surveys of radio sources at cm wavelengths (Windhorst et al. 1985; Condon & Mitchell 1984; Fomalont et al. 1984; Partridge et al. 1986; Fomalont et al. 1988; Fomalont et al. 1991; Windhorst et al. 1993) to derive essentially model independent estimates of Poisson fluctuations down to scales $\simeq 30''$. Our predictions are made uncertain only by the required extrapolation of the radio source counts (which are directly measured at $\lambda \gtrsim 3$ cm) to mm wavelengths. There is, however, sufficient spectral information to substantially reduce such an uncertainty (at least for the dominant source populations).

At $\nu \gtrsim 100$ GHz, the contribution of far-IR selected sources, whose emission is dominated by interstellar dust, starts to be appreciable. Since our knowledge of the counts of extragalactic far-IR sources still relies on the $60\mu\text{m}$ IRAS survey, their contribution to CMB anisotropies is difficult to estimate due to the lack of data at faint fluxes ($\lesssim 50$ mJy) and to the yet poor knowledge of cold dust components in galaxies. Estimates of the $\Delta T/T$ levels due to Poisson distributed far-IR sources has been calculated by Franceschini et al. (1989,1991) while Wang (1991) focused on the $\Delta T/T$ contribution given by a non-Poisson distribution of far-IR galaxies.

Correlations in the spatial distribution of extragalactic radio sources, for which there is increasing evidence, provide an additional signal to the background anisotropies. The amplitude of the effect is difficult to estimate, but preliminary indications of substantial clustering for radio galaxies of medium radio power (Peacock & Nicholson, 1991) suggest that the non-Poisson contribution to fluctuations may be important on some angular scales. As for far-IR/sub-mm sources, the information on their clustering properties still relies on the IRAS survey at 60 and $100\mu\text{m}$. Since dust emission from galaxies gives a great contribution to the far-IR/sub-mm background, a non-Poisson distribution of sources could give non negligible contributions to CMB anisotropies at sub-mm wavelengths. Anyway, analyses of the IRAS data have shown that the correlation length of disk galaxies is smaller than that of optically or radio selected galaxies, while there is no up-to-now evidence of correlations for early-type IRAS galaxies. Thus, the $\Delta T/T$ contribution due to clustered sources in the far-IR/sub-mm wavelength range is smaller than in the radio and we will only briefly comment on this point.

2 ANISOTROPIES DUE TO GALACTIC EMISSION

At present, full-sky radio maps at resolutions comparable to (or better than) those discussed here are only available at decimeter wavelengths (Haslam et al., 1982; Reich & Reich, 1982). Unfortunately, they are rather poorly calibrated, with a 5–10% typical uncertainty on temperature variations. The situation is better in the far-IR/sub-mm domain, where the properly calibrated 100 μm IRAS and 240 μm *COBE* DIRBE maps are well suited to predict galactic anisotropies. In this case, the problem resides in the required large spectral extrapolation of energy distributions steeply varying with the wavelength.

A comprehensive analysis of the confusion noise given by galactic synchrotron radiation (GSR) and dust emission has been recently performed by Banday & Wolfendale (1990; 1991a,b) and by Banday et al. (1991). Their main conclusions are the following. *a)* The GSR fluctuations at frequencies higher than ~ 20 GHz should be small enough ($\Delta T/T \lesssim 5 \times 10^{-6}$) not to dominate the cosmological effect. Therefore, with some improvements in the GSR noise predictions and in the technical quality of the observations, the adoption of frequencies $\gtrsim 30$ GHz would allow to detect true CMB anisotropies. *b)* As for the galactic dust, they took into account the nature of the dust emission, in terms of grain properties and environment and discussed the overall Galactic emission, focusing on high galactic latitudes where the dust is heated by the general interstellar radiation field. Considering GSR and galactic dust noise together, they found that the lowest $\Delta T/T$ achievable, away from currently known cirrus complexes, is $\sim (2 - 4) \times 10^{-6}$ at ~ 90 GHz on the angular scales of the *COBE* DMR experiment.

Another estimate of the $\Delta T/T$ levels due to the Galaxy has been given by Masi et al. (1991). They estimated the general spectrum of the diffuse galactic emission from available experimental data. Moreover, by a pixel-to-pixel correlation between the 408 MHz map (Haslam et al., 1982) and the IRAS 100 μm emission and avoiding low galactic latitude regions ($|b| > 5^\circ$) they found a very significant spatial correlation between the cm radio and the far-IR emission in our Galaxy. Their main result is that there is a spectral window ($0.5 > \lambda > 0.11$ cm) and many spatial windows (5–10% of the sky) where anisotropies due to the galactic emission keep below $\Delta T/T \sim 2 - 4 \times 10^{-6}$, on angular scales $0.5^\circ \lesssim \theta \lesssim 5^\circ$.

Concerning the free-free emission, the only full-sky maps available up to now at frequencies where free-free should dominate are those provided by *COBE* DMR. The analyses of

Bennett et al. (1992, 1994) of the DMR data show that their “pure free–free” map at 53 GHz has a galactic latitude dependence of $T_A^{ff}(\mu K) = (10 \pm 4)\text{cosec}|b|$ for $|b| > 15^\circ$. On the other hand, probes of the warm ($T \approx 10^4$ K), low density ($n \approx 10^{-1} \text{ cm}^{-3}$) ionized medium such as H_α , C^+ and N^+ are relevant indicators of the hydrogen free–free continuum at intermediate to high galactic latitudes (Reynolds, 1992; Bennett et al., 1992, 1994) and the associated free–free emission at radio frequencies can then be directly calculated from the observed H_α intensity.

Using a ~ 0.8 deg beam, Reynolds (1992) found that the average free–free intensity at high galactic latitudes predicted by the H_α background is 1.2×10^{-6} and 6×10^{-6} times that of the CMB at $\lambda=3.3$ and 9.5 mm, respectively. The same author also derived an amplitude of the free–free cosecant law a factor of ~ 3 smaller than that obtained from the *COBE* full sky maps. This can be understood by considering that Reynolds picks up location that are free from discrete sources, while *COBE* does not make any source exclusion (see Bennett et al., 1992). Anyway, since bright spots could be identified and subtracted with high resolution observations, this could be also interpreted in terms of a smaller free–free contribution to CMB fluctuations at intermediate to small angular scales ($\lesssim 1^\circ$).

2.1 Sky Fluctuations at High Galactic Latitude

The Gautier III et al. (1992) spatial power spectrum analysis of the sky surface brightness provided by the IRAS 100 μm maps and scans is a useful tool to estimate the confusion noise due to infrared cirrus. By this formalism, and fixing the average sky brightness at 100 μm , one can easily calculate the $\Delta T/T$ levels at different angular scales and for different configurations of the observing reference aperture. Then, adopting a suitable emission spectrum, it is possible to extrapolate the estimated $\Delta T/T$ levels to longer wavelengths (see also Franceschini et al., 1991) under the assumption that the different emission components in our Galaxy are *spatially correlated* at different angular scales. This correlation is clearly associated with global properties of the ISM in the galactic disk (i.e. energy balance among the different processes) whereas it cannot be directly translated to every single observed region of the Galaxy without a critical discussion. There are likely local changes in the synchrotron emission due to fluctuations in the distribution of the ISM from supernova shocks, winds from OB stars and variations in the irregular component of the galactic magnetic field (Banday

et al., 1991; Bennett et al., 1992). At the same time, there is some evidence of a more diffuse distribution for the free-free component (Hancock et al., 1994). Anyway, the diffuse ionized hydrogen appears correlated with the dust emission at high galactic latitude not only as regards the diffuse emission but also in local patches of the sky (HII regions have been clearly identified associated with O and B stars and bursts of star formation). As for the synchrotron component, it is very strongly correlated with the dust emission as proved by radio and IRAS observations of disk galaxies (i.e. de Jong et al., 1985; Helou et al., 1985) and, for our Galaxy, by the analysis of Masi et al. (1991), who found a strong correlation on a pixel size of $2^\circ \times 2^\circ$, comparable with the angular scales of interest here. Moreover, at high galactic latitude, the column density of the HII is found to range between 26% and 63% of that of the HI (Reynolds, 1991) while this latter shows a well known correlation with the 100 μm dust emission (Boulanger & Perault, 1988). For all these reasons, we think that our assumption is likely to give at least a first-order estimate of the anisotropies due to the galactic foreground.

To fix the average sky brightness, B_0 , at high galactic latitude we consider that 10% of the sky has $B_0 \leq 1.5$ MJy/sr at 100 μm . Furthermore, as reported by Lockman et al. (1986) about 8% of the sky has HI column densities $N_H \lesssim 1.5 \times 10^{20} \text{ cm}^{-2}$. Using the correlation between 100 μm and HI emission derived by Boulanger & Perault (1988) such column densities would imply a sky brightness < 1.3 MJy/sr. Considering the capabilities of future multi-channel high sensitivity experiments in the sub-mm domain, which should allow to subtract – at least partially – the dust emission, we have adopted a 100 μm average residual sky brightness which is 0.4 MJy/sr, $\sim 30\%$ of the previously quoted value.

To estimate the confusion noise in the sub-mm domain we adopted the model of Rowan–Robinson (1992) to describe the far-IR/sub-mm spectrum of the Galaxy. By incorporating very large grains to explain excess emission at millimetre wavelengths, the model presented by Rowan–Robinson provides an excellent fit to the interstellar extinction curve and to the far-IR spectrum of dust in our Galaxy. In particular, we used his fit to the emissivity towards the galactic pole (Rowan–Robinson, 1992, Figure 3a) to extrapolate down in frequency the $\Delta T/T$ levels calculated at 100 μm . The resulting dust spectrum presents a frequency dependence $\nu^\alpha B(\nu)$ with $\alpha = 1.5\text{--}1.7$ and a steepening to $\alpha \simeq 2$ at lower frequencies ($\nu \lesssim 400\text{--}500$ GHz).

As regards the estimated galactic noise in the radio, at $\lambda \gtrsim 3$ mm, we have avoided to

use the radio maps at lower frequencies due to their poor calibration and for they suffer from both striation and baseline problems which hinder the prediction of anisotropy levels. We assumed that the very tight correlation between the radio centimetric and far-IR/sub-mm emissions for the galactic disc component (de Jong et al., 1985 and references therein; Rowan-Robinson, 1992) holds also at high galactic latitude at intermediate angular scales ($\sim 1^\circ$) which seems to be confirmed by the analysis of Masi et al. (1991). To extrapolate our predictions from 1.4–5 GHz up to 90–100 GHz we have then adopted the spectral indices of the free-free and synchrotron emissions estimated by Bennett et al. (1992), assuming that synchrotron and free-free give an equal contribution to the total galactic emission at $\simeq 30$ GHz and $B = 1.4\mu\text{G}$ for the magnetic field strength.

In spite of the uncertainties, due to the assumed angular and spectral dependence, our estimates of the galactic noise agree with previously published results based on quite different and independent assumptions (see §4.1).

3 ANISOTROPIES DUE TO EXTRAGALACTIC SOURCES

3.1 Sky Fluctuations from Randomly Distributed and Clustered Sources

Since the problem has been extensively discussed in the literature, we will only sketch it here. All our estimates are based on the assumption of “point-like” sources (Rowan-Robinson & Fabian, 1974): because the angular scales of interest here are larger than the typical source size, we can be confident that this assumption should not affect our predictions. We defer to Franceschini et al. (1989) and references therein for a thorough discussion on fluctuations from randomly distributed sources.

The contribution to the intensity fluctuations from clustered source populations can be computed under rather general hypotheses. The formalism adopted has been developed and discussed by De Zotti et al. (1990, 1994) and Martín-Mirones et al. (1991) and we will defer to these articles for all the relevant formulae.

While Poisson noise is dominated by sources counts at fluxes corresponding to ~ 1 source per beam, hence by sources in a *limited flux interval* (the most abundant fainter ones producing only smaller contributions), conversely, *all fluxes* contribute to non-Poisson noise, which is then dominated by *the faintest and more numerous sources which do actually cluster* (see Barcons, 1992 for more details).

Pushing the detection threshold to fainter and fainter limits will then reduce the Poisson contribution to the sky fluctuations at a fixed angular scale more than the additional one due to the clustering. So, if *all sources* do cluster, even with a relatively small clustering length, r_0 , we can have a $(\Delta T/T)_{cl}$ level of the same order of the Poisson one.

3.2 Radio Source Counts and their Extrapolation to high Frequencies

Our predictions of the expected fluctuation levels due to discrete sources are based on the interpretation of deep survey data at cm wavelengths proposed by Danese et al. (1987). Adopting a simple evolutionary scheme, they have been able to explain the flattening of the 1.4 and 5 GHz source counts, the identification statistics and redshift distributions at sub-mJy flux levels, as well as data at bright flux densities.

All available analyses (e.g. Impey & Neugebauer 1988) have clearly shown that compact sources, which dominate the source counts at wavelengths $\lambda \leq 1$ cm, have spectral indices keeping “flat” ($\alpha \simeq 0.0$, although with some scatter) at least up to ~ 100 GHz, bending down only at $\sim 10^{12}$ Hz. A further test on the high frequency behaviour of compact radio sources can be obtained by comparing predictions on source counts with data from high frequency complete surveys. Franceschini et al. (1989) have compared 10 GHz source counts with model predictions extrapolated to this frequency with spectral indices of flat-spectrum sources above 2.4 GHz allowed to vary from 0 to 0.4: they found that the 10 GHz data are consistent with an average spectral index ~ 0 for compact sources.

In view of the above, we have considered, for compact sources, the case of $\alpha = 0$ over the whole frequency range of interest here. Above $\nu = 100$ GHz we have assumed that spectra break to $\alpha = 0.7$. For the steep spectrum sources, we have adopted the radio power – spectral index relation determined by Peacock and Gull (1981).

3.3 The Contribution of Far – IR Sources

Far-IR selected sources, whose emission is dominated by the cold and warm dust components, are likely to originate high CMB fluctuations in the sub-mm domain, due to their rapidly increasing integrated intensity, $\nu I(\nu)$, if compared to the fast decrease of the CMB shortwards of the peak at ~ 1 mm. At wavelengths longer than the CMB intensity peak, far-IR/sub-mm sources still give a non-negligible contribution, at least down to $\sim 80 - 90$ GHz, depending on the adopted far-IR to sub-mm spectral behaviour and on the angular scale. Extrapolations

to still longer wavelengths give negligible contributions to the predicted $\Delta T/T$ levels for any reasonable thermal dust spectrum.

We adopt here two different descriptions of the cosmological evolution of far-IR sources, in order to provide a confidence interval to the predicted $\Delta T/T$ level. The first one is the model by Franceschini et al. (1988), assuming a strong cosmological evolution of galaxies with significant star formation activity (Actively Star Forming galaxies), while the second one predicts appreciable cosmological evolution of both late- and early-type galaxies (see Franceschini et al. 1994 for more details).

Apart from ellipticals and S0s, for which there is virtually no information, the spectra of all other galaxy populations in the far-IR and sub-mm domains are dominated by thermal dust emission. The first model adopts the far-IR/sub-mm spectrum of Kreysa & Chini (1989), which is based on a very high ($f_{1.25\text{ mm}}/f_{100\mu\text{m}} \sim 1.5 \times 10^{-2}$ flux ratio for normal galaxies, 3-5 times higher than found by Andreani & Franceschini (1992)). The spectra adopted in the second, more conservative, model have been derived from the photometric model by Xu & De Zotti (1989) for Spiral and ASF galaxies, which is based on available IRAS and sub-mm data. These spectra turn out to be in good agreement with recent millimeter observations of a complete sample of *IRAS* selected galaxies (Andreani & Franceschini, 1992). The far-IR spectrum of Seyfert galaxies has been derived from observations of AGNs by Chini et al. (1989) and Ward et al. (1987) (see Franceschini et al. 1991, for more details).

The first model, to be taken as a somewhat extreme limiting case, gives the highest integrated background due to sources still compatible with current FIRAS upper limits on the extragalactic component (see Wright et al. 1993). We believe that the second one, based on a broad-band spectral description for galaxies which takes into account in detail the evolution of the thermal dust emission with cosmic time (Mazzei et al. 1992, 1994), should more realistically predict the average sky noise due to galaxies.

4 RESULTS AND DISCUSSION

We summarize in Figure 1 our predictions on confusion noise due either to galactic emission as well as to extragalactic discrete sources. The three panels refer to three angular scales (2° , 0.5° , and $10'$) covering the most relevant range for current and future experiments on CMB anisotropies. As reminded in §1, these angular scales provide informations on primordial

density fluctuations on scales corresponding to the observed large-scale structures, allowing to study the physics of structure formation. The figure covers the whole frequency range (20-500 GHz) around the CMB intensity peak to identify the most suitable frequencies for future experiments.

4.1 Galactic Noise

Our current estimate, which relies critically on the Gautier III et al. (1992) analysis, and in particular on their claimed dependence of the galactic noise on the angular scale ($\Delta I/I \propto \theta^{0.45}$), shows that the Galaxy and the extragalactic sources give comparable contributions to the CMB anisotropies for $\theta \simeq 0.5$ deg, while at smaller scales extragalactic sources dominate. At scales $\gtrsim 1^\circ$ the galactic emission gives by far the dominant contribution to the confusion noise (upper panel of Figure 1).

We also confirm that the lowest $\Delta T/T$ levels due to galactic synchrotron, free-free and dust radiation are found around $\nu \sim 100$ GHz. In particular, our best guess at 90 GHz results in good agreement with that obtained by Banday & Wolfendale (1991) by convolving the IRAS HCON2 maps with the *COBE* beam size of 7° and assuming the Lubin's et al. (1990) dust emission spectrum (if we take into account the different angular scales examined in the two cases). A similar agreement is also found with the Bennett et al. (1992) *COBE* DMR estimate of the 90 GHz anisotropy level due to high galactic latitudes dust, giving $\Delta T_A \simeq 2.3\text{--}6.5 \mu\text{K}$. Albeit uncertain within a factor $\sim 2\text{--}3$, due to the meagre information available on the spatial distribution and correlations of the weak high latitude emission of the Galaxy, our current estimates indicate that the galactic confusion noise should not be greater than $\Delta T/T \sim 10^{-6}$, at least in the best spectral window.

4.2 Extragalactic Sources

4.2.1 Poisson fluctuations

Concerning the contribution of randomly distributed sources, it is clear that the choice of smaller scales does not help in reducing their confusion noise. As already discussed by Franceschini et al. (1989; 1991), the shape of the radio and far-IR source counts is such that the highest $\Delta T/T$ levels due to extragalactic source populations are reached at intermediate to small angular scales ($\theta \lesssim 10'$). For this reason, if radio and far-IR selected sources give a negligible contribution to CMB fluctuations on the large angular scale of the *COBE* DMR

experiment, at smaller scales they turn out to be increasingly important and for angular scales $\lesssim 20'$ they are probably the dominant foreground noise.

In particular, we obtain $(\Delta T/T) \simeq 4 - 5 \times 10^{-6}$ at ~ 30 GHz, summing up the contributions of all the undetected sources up to the 5σ detection limit: a value very close to the level expected from scale-invariant primordial fluctuations. At higher frequencies, ~ 50 -90 GHz, we have a better situation, with $\Delta T/T \sim 1 - 2 \times 10^{-6}$, i.e. sufficiently small to only marginally affect the detection of intrinsic CMB anisotropies. This decrease of the predicted fluctuation levels at higher frequencies is due both to the fading of steep-spectrum radio sources, which give a progressively smaller contribution to the counts, and to the ordinary K-correction in high-redshift bright “flat”-sources observed beyond the steepening of the spectrum at 100 GHz.

Far-IR selected sources start to contribute to Poisson CMB fluctuations at, say, 80-100 GHz, strongly depending on the assumed dust spectrum, as discussed in §3.3. For any reasonable choice of the spectrum, they do not contribute more than 10 – 20% to the total predicted fluctuations at $\theta = 30$ arcmin. On the other hand, they start to dominate at smaller angular scales ($\theta \lesssim 5 - 10$ arcmin), with a contribution at $\theta = 1'$ a factor ~ 5 higher than that coming from radio selected sources. The very steep dust emission spectra and the few data available in the sub-mm region on the emission of extragalactic sources suggest to avoid wavelengths shorter than $\lambda \simeq 1.2 - 1.3$ mm to search for intrinsic CMB anisotropies. Indeed, Poisson fluctuations rapidly increase for $\lambda < 1.5$ mm: at $\lambda \simeq 1$ mm their level, although uncertain to within a factor of ~ 3 because of the different choices of the cold-dust spectrum and of the cosmological evolution of sources, is again well above $(\Delta T/T) \simeq 10^{-6}$ at $\theta \simeq 10'$, while keeping just below the 10^{-6} level for $\theta = 30'$.

4.2.2 Non – Poisson fluctuations

Our estimates of the non-Poisson contribution to $\Delta T/T$ are all based on the analysis of large scale clustering of radio galaxies done by Peacock & Nicholson (1991). They have found that radio source cluster, at least for a particular power range ($\log P_{1.4 \text{ GHz}} \simeq 22.5 - 24.5 h^{-2} \text{ WHz}^{-1} \text{ sr}^{-1}$). Since we have assumed that all galaxies contributing to the background anisotropies do cluster, our estimates could be taken as a safe upper limit. On the contrary, if we consider that only sources in the power ranges for which clustering has been detected

do actually cluster, then the predicted contribution of clustering to the fluctuation level will be significantly reduced for the same choice of the other relevant parameters.

What is found is that the non-Poisson contribution to the anisotropies is usually negligible, being a factor of $\sim 2.5 - 3$ below the Poisson noise even adopting the highest reasonable value for the clustering length. Owing to the different dependence on the assumed flux limit (see §3.1), only for experiments in which source identification and subtraction is performed down to flux levels much fainter than the 5σ detection threshold and assuming the same clustering length as found by Peacock & Nicholson for all source luminosities, would the fluctuations due to clustered sources be important at the angular scales of interest here.

Concerning sub-mm sources, no information is available on their clustering properties. Anyway, since far-IR sources selected from the *IRAS* Point Source Catalogue seem to be characterized by a very small clustering length, 3-4 times smaller than found for radio sources, we can be confident that their non-Poisson contribution to the CMB fluctuations keeps always negligible.

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References

- Andreani, P., & Franceschini, A. 1992, *A&A*, 260, 89
- Banday, A.J., & Wolfendale, A.W. 1990, *MNRAS*, 245, 182
- Banday, A.J., & Wolfendale, A.W. 1991a, *MNRAS*, 248, 705
- Banday, A.J., & Wolfendale, A.W. 1991b, *MNRAS*, 252, 462
- Banday, A.J., Giler, M., Szabelska, B., Szabelski, J., & Wolfendale, A.W. 1991, *ApJ*, 375, 432
- Barcons, X. 1992, *ApJ*, 396, 460
- Bennett, C.L., et al. 1992, *ApJ*, 396, L7
- Bennett, C.L., et al. 1994, *ApJ*, in press
- Bennett, C.L., Hinshaw, G., Banday, A., Kogut, A., Wright, E.L., Loewenstein, K., & Cheng, E.S. 1993, *ApJ*, 414, L77
- Boulanger, F., & Perault, M. 1988, *ApJ*, 330, 964
- Brandt, W.N., Lawrence, C.N., Readhead, A.C.S., Pakianathan, J.N., & Fiola, T.M. 1994, *ApJ*, in press
- Chini, R., Krugel, E., Kreysa, E., Gemund, H.-P. 1989, *A&A*, 216, L5
- Condon, J.J., Mitchell, K.J. 1984, *AJ*, 89, 610
- Danese, L., De Zotti, G., Franceschini, A., & Toffolatti, L. 1987, *ApJ*, 318, L15
- de Jong, T., Klein U., Wielebinski R., Wunderlich, E. 1985, *A&A*, 147, L6
- De Zotti, G., Persic, M., Franceschini, A., Danese, L., Palumbo, G.G.C., Boldt, E.A., & Marshall, F.E. 1990, *ApJ*, 351, 22
- De Zotti, G., Franceschini, A., Toffolatti, L., & Mazzei, P., 1994, *Astrophys. Lett & Comm.*, submitted
- Fomalont, E.B., Kellermann, K.I., & Wall, J.V. 1984, *ApJ*, 277, L23
- Fomalont, E.B., Kellermann, K.I., Anderson, M.C., Weistrop, D., Wall, J.V., Windhorst, R.A., & Kristian, J.A. 1988, *AJ*, 96, 1187
- Fomalont, E.B., Windhorst, R.A., Kristian, J.A., & Kellermann, K.I. 1991, *AJ*, 102, 1258
- Franceschini, A., Danese, L., De Zotti, G., & Toffolatti, L. 1988, *MNRAS*, 233, 157
- Franceschini, A., Toffolatti, L., Danese, L., & De Zotti, G. 1989, *ApJ*, 344, 35

- Franceschini, A., Toffolatti, L., Mazzei, P., Danese, L., & De Zotti, G. 1991, A&A Suppl. 89, 285
- Franceschini, A., Mazzei, P., Danese, L., & De Zotti, G. 1994, ApJ, in press
- Gautier III, T.N., Boulanger, F., Perault, M., & Puget, J.L. 1992, AJ, 103, 1313
- Hancock, S. et al., 1994, Nature, 367, 333
- Haslam, C.G.T., et al., 1982, A&AS, 47, 1
- Helou, G., Soifer, B.T., Rowan-Robinson, M. 1985, ApJ, 298, L7
- Impey, C.D., & Neugebauer, G. 1988, AJ, 95, 307
- Kreysa, E. & Chini, R. 1989, Proc. *3rd ESO/CERN Symp. on Astronomy, Cosmology and Fundamental Physics*, eds. Caffo, M., Fanti, R., Giacomelli, G., Renzini, A.. Kluwer, Dordrecht, p.433.
- Lockman, F.J., Jahoda, K., & McCammon, D. 1986, ApJ, 302, 432
- Lubin, P., Meinhold, P.R., & Chingcuanco, A.O., 1990, The Cosmic Microwave Background – 25 Years Later, eds. Mandolesi, N. & Vittorio, N., p.115
- Masi, S., de Bernardis, P., De Petris, M., Epifani, M., Gervasi, M., & Guarini, G. 1991, ApJ, 366, L51
- Martín-Mirónes, J.-M., De Zotti, G., Boldt, E.A., Marshall, F.E., Danese, L., Franceschini, A., & Persic, M. 1991, ApJ, 379, 507
- Mather, J.C. et al. 1990, ApJ, 354, L37
- Mather, J.C. et al. 1993, ApJ, in press
- Mazzei, P., Xu, C., & De Zotti, G. 1992, A&A, 256, 45
- Mazzei, P., De Zotti, G., & Xu, C. 1994, ApJ, in press
- Page, L.A., Cheng, E.S., & Meyer, S.S. 1990, ApJ, 355, L1
- Partridge, R.B., Hildrup, K.C., & Ratner, M.I. 1986, ApJ, 308, 46
- Peacock, J.A., & Gull, S.F. 1981, MNRAS, 196, 611
- Peacock, J.A., & Nicholson, S.F. 1991, MNRAS, 253, 307
- Reich, P. & Reich, W. 1986, A&AS, 63, 205
- Reynolds, R.J. 1991, in IAU Symp. 144, The Interstellar Disk-Halo Connection in Galaxies, ed. H.Bloemen (Dordrecht:Kluwer), p.67
- Reynolds, R.J. 1992, ApJ, 392, L35
- Rowan-Robinson, M., 1992, MNRAS, 258, 787

- Rowan-Robinson, M., & Fabian, A.C. 1974, MNRAS, 167, 419
- Smoot, G.F., et al. 1992, ApJ, 396, L1
- Xu, C., & De Zotti, G. 1989, A&A, 225, 12
- Wang, B. 1991, ApJ, 374, 465
- Ward, M.J., Elvis, M., Fabbiano, G., Carleton, N.P., Willner, S.P., Lawrence, A. 1987, ApJ, 315, 74
- Windhorst, R.A., Miley, G.K., Owen, F.N., Kron, R.G., & Koo, D.C. 1985, ApJ, 289, 494
- Windhorst, R.A., Fomalont, E.B., Partridge, R.B., & Lowenthal, J.D. 1993, ApJ, 405, 498
- Wright, E.L., et al. 1992, ApJ, 396, L13
- Wright, E.L., et al. 1993, ApJ, in press

FIGURE CAPTION

Figure 1 Estimated fluctuation levels, in terms of the thermodynamic temperature $\Delta T/T$, due to the galactic polar emission and to the extragalactic sources. The three panels refer to different angular scales. The three plotted curves indicating the galactic anisotropy levels refer to the following choices for the dust emission spectrum: the central one refer to the Rowan–Robinson (1992) model (see text for more details); the upper one adopts a less steep dust emissivity index ($\alpha \simeq 1$) useful to give an upper limit to galactic anisotropies and accounting for a possible low–frequency excess at high galactic latitude (due to large dust grains having an enhanced emissivity) like that seen from many groups close to the galactic plane (i.e. Page, Cheng & Meyer, 1990); the lower one assumes a steeper dust emissivity index ($\alpha = 2$) and an higher dust temperature ($T \simeq 24$ K). The two curves indicating the Poisson noise levels due to discrete extragalactic sources refer to a source detection limit $x_c = 5\sigma$ and to different models for the evolution of the cold dust. The higher $\Delta T/T$ level corresponds to the model by Franceschini et al. (1988) assuming strong cosmological evolution of the most luminous far–IR selected sources (ASF galaxies), while the lower one refers to a moderate cosmological evolution of both late- and early-type galaxies (Franceschini et al., 1994). Both models give integrated intensities $I(\nu)$ still compatible with the recent *COBE* FIRAS upper limits on the CMB residuals in the sub–mm domain (Mather et al., 1993; Wright et al. 1993) but the higher is close to infringe the FIRAS limits. The four frequencies foreseen for the COBRAS experiment, 31.5, 53, 90 and 125 GHz, are also indicated by the dotted vertical lines.

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